FLOOD-PRONE AREAS AND THEIR MANAGEMENT ON THE LOWER REACH OF THE YELLOW RIVER[1]

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As a dry sub-humid area, the North China Plain relies heavily on water supply from the Yellow River to support its agricultural and other economic sectors. It is estimated that an average of 10.8 billion m^3 of water is drawn from the river to irrigate the farmlands in the plain each year (You 1996). Largely due to the construction of reservoirs and diversion works on the upper and middle reaches, water cutoff events on the lower reach of the Yellow River become frequently and the cutoff duration shows an increasing tendency in recent years. Water cutoff happened in 21 years out of the 27 years from 1972 to 1998. In 1997, there were 330 days without any water flowing into the sea from the Yellow River. This results in a serious water shortage problem in the North China Plain and has alarmed both the central and local governments.

This paper, however, discusses another problem of the North China Plain, dike-outbreak flooding, which is connected to the shriveled channel issue of the Yellow River. The impact of flooding may be not felt so widely in terms of its spatial scale but is much hazardous than the water shortage issue. The problem is that the danger has not yet been paid appropriate attention. Literature on flood plain management in the area are extremely lacking compared with erosion and runoff control.

I. POSSIBILITY OF DIKE-OUTBREAK FLOODING

Being called as a "suspending river" in China, the Yellow River is perched above the surrounding flood plain on its lower reach, with its riverbed 4 - 8 m higher than the plain outside the dikes. In the last 2,500 years, the river has changed its course 26 times and flooded some 1,500 times (Ye 1994). Fifty more years may pass without any dike-outbreak flooding in summer and autumn seasons thanks to the construction of reservoirs on the upper and middle reaches and three times of dike reinforcing and elevation on the lower reaches. It cannot be concluded, however, that the danger of dike-outbreak flooding has been sufficiently prevented. In fact, the danger has been exacerbated in recent years due to a number of factors. These include:

1. Low flood control standard The present flood control standard of the Yellow River on its

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lower reach is 22,000 m^3s^{-1} at Zhengzhou Hydrometric Station (probability 2.2%), taking all the reservoirs, dikes and flood detention works into account. It is estimated that the discharge of the largest possible flood is as high as 55,000 m^3s^{-1} based on historical data and a statistical analysis (Liu and Liang 1988). Discharge of the recorded large flood in 1761 might be 32,000 m^3s^{-1} and that in 1843 might be 36,000 m^3s^{-1} (Shi and Wang 1988).

2. Poor quality of the flood control works There are many vulnerable spots in the flood control works, especially in the 1,300 km long dikes on the lower reach. The serious problems include loose dike bases, seepage, crevices and animal caves. Length of the danger dike segments makes up over 20% of the long dikes. Thus it is possible for a common flood to break the dike and result in a flood hazard in the surrounding plain.

3. Decreasing flood transmission capacity of the river channel Owing to the construction of reservoirs on the upper reach and irrigation development in the whole basin, the discharge of in the main channel of the Yellow River has decreased and sedimentation on its lower reach has increased considerably in recent years. As a result, the water level with the same discharge is much higher than before. For example, the water level of a 6,260 m^3s^{-1} flood on August 16 in 1992 is 0.34 m higher than that of a 15,300 m^3s^{-1} flood in 1982 (Zhang 1993).

4. Unstable main current in the wide river course Because of the low gradient along stream, the main current of the river in its wide course segments varies frequently across the channel. Consequently, the dike is often eroded and lashed by the main current. This was the major cause of dike-outbreak flooding in the history.

5. Increasing danger of earthquakes The lower reach of the Yellow River is located in a strong faulting area. It is predicted that the earthquake intensity in a large part of the area is 7 - 8 magnitude within the future 50 years, and there is also a possibility for earthquakes of 9 magnitude in some areas (SBS 1990). Liquefaction of dike foundation induced by earthquake is also a major cause of dike-outbreak flooding. A typical example was the flood hazard in Shandong Province in 1668 (Guo 1993).

In the last 40 years, flood control on the lower reach of the Yellow River relies heavily on the large engineering works that aims at keeping floods within the dikes, while the flood-proof measures in the vast flood plain are quite poor. In this connection, the only option in the flood plain will be loss absorption while a dike-outbreak flooding occurs (Burton, Kates and White 1978). The protection effect of the large engineering measures is questionable while the above analysis is considered. High silt content is the source of flooding threat on the lower reach of the Yellow River. The threat will never be over since the soil conservation in the Loess Plateau is not an easy work and the thorough control of soil erosion there is theoretically questionable. Thus flood plain management must be given the same importance as the large flood control engineering works on the upper and middle reaches and along the river on the lower reach.

II. THE FLOOD-PRONE AREA

The spatial extent of the flood plain under the direct influence of dike-outbreak floods depends on a lot of factors. Based on an analysis of the possible dike-outbreak location, peak discharge and total volume of the flood and the terrain of the flood plain, the flood-prone area in the North China Plain is delineated as shown in Figure 1. The area is bounded by the Wei River on the northwest, the Ying River on the southwest, the Huai River on the south and the Great Canal on the east. Within this region, there is an area with a relatively high terrain surrounding the abandoned Yellow River, which will be not inundated.

The total area of the delineated flood-prone region is about 117,900 km^2. It consists of 108 counties in Henan, Shandong, Anhui and Jiangsu Provinces and has a population of 71.04 million in 1992. Population density of the area is as high as 602 $person.km^{-2}$. Traditionally, this is an agricultural area with an economy less developed than the coastal areas. However, its communication facilities, energy industry and agriculture hold important places in the country. Two of the five largest oil fields in China are located in the area. The area produces one fifth of the country's cotton and 6 - 7% of grain, edible oils and meat (Table 1). As being located at the central part of China, it is connected to most major economic centers of the country by railway and highway networks. There are also a number of large new industrial cities in the area, such as Zhengzhou, Jinan, Kaifeng, Xinxiang and Binzhou. Thus, once a dike-outbreak flood occurs, there will be heavy losses. Based on an investigation of the economic loss in a flood hazard in Anhui Province in 1992, it is estimated that a dike-outbreak flood will make a total loss as high as $10 billion in the flood plain on the lower reach of the Yellow River if it happens in 1996.

Table 1

Output of the major farming products in the flood-prone area on the lower reach of the Yellow River

Product	Output (1000 ton)	Proportion in the country's total (%)
Grain	31011	7.0
Cotton	959	21.3
Edible oil	958	5.8
Meat	1771	6.0

Source: Governmental statistics data in 1992.

III. CLASSIFICATION AND DANGER MAGNITUDE APPRAISAL FOR THE FLOOD-PRONE AREAS

The principal purpose of flood plain management is to reduce flood losses as much as possible. Losses in a dike-outbreak flood disaster is determined by three groups of factors, i.e., location, landscape and socio-economic conditions. An area with a location close to the burst place, landscape favorable to flood spreading and socio-economic conditions being easily attacked by floods will have a larger loss than other areas. A classification and danger magnitude appraisal for the flood-prone areas based on analysis of these factors will help the determination of key areas in flood abatement planning and appropriate measures for different areas.

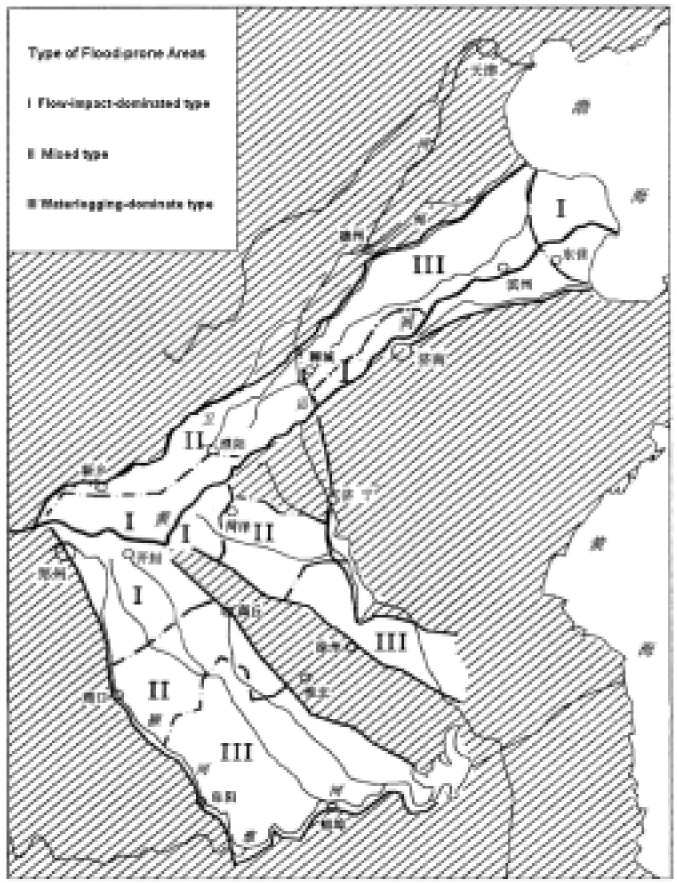

Fig. 1 Spatial extent and a classification of the flood-prone areas on the lower reach of the Yellow River

III.1 Classification of the Flood-prone Areas

Generally, the regional differentiation of disaster loss caused by dike-outbreak floods has the following characteristics:

1. In the upper parts of alluvial fans, the flood flows have not steady courses. The flow velocity, silt content and depth of flood are large, but flooding duration is relatively short. Because of the large impact force of flood, soil washout and sedimentation in farmlands and the destruction of buildings are more serious than the other parts of flood plain.

2. In the middle and lower parts of alluvial fans, the flood flows have fixed courses, which may be occupied from other rivers. The inundated area in these parts of flood plain is limited to the surrounding area of flood flows, and flood damage in a locale is related to its distance from the main flood currents. The flow velocity, silt content and depth of flood and the disaster loss become increasingly large while approaching the main flood currents.

3. In the fringe area of alluvial fans, the slope gradient of flood plain is very low and then the

plain. Inundating duration is long but the flow velocity and depth of flood are relatively low.

Based on the above analysis, hazards caused by dike-outbreak floods at different locale of flood plain can be divided into three general types: 1) flow-impact-dominated type; 2) waterlogging-dominated type; 3) mixed type. Correspondingly, the flood-prone areas on the lower reach of the Yellow River can be classified into three types (Figure 1), where different flood abatement measures should be implemented.

Some 7 possible break segments of the dikes along the Yellow River were identified based on an analysis of the dike stability. Flow-impact-dominated areas on the map illustrated in Figure 1 are adjacent to these possible break segments. They are usually old burst alluvial fans of the river and distributed as long belts with a width of 10 - 40 km out of the dikes. Because of the large slope gradient (1/3,000) and a close locale to the dike-break sites, these areas constitute the most dangerous parts of the flood plain. Most rivers in the North China plain have low drainage capacity due to serious sedimentation and low slope gradient (1/12,000 - 8,000). Flood control standards in the areas on the lower reaches of these rivers are very low, e.g., the area surrounding the Huai River would be inundated while a flood of 30% frequency occurs. The regions labeled Type III in Figure 1 belong to such areas.

III.2 Danger Magnitude Appraisal for the Flood-prone Areas

Damage caused by flooding is not only determined by flow velocity, silt content and inundating duration of the flood, but also related to the socio-economic conditions of the flood-prone area, such as population density, development level and flood-proof capability. The impact of flood is often reflected on casualties, economic loss, destruction of social services and environmental degradation, most of which is difficult to predict quantitatively. In this paper, fixed assets per unit area, annual income per capita, annual agricultural and industrial output per unit area are used to evaluate the danger magnitude of each county, reflecting the relative extent of the economic loss in a possible dike-outbreak flood.

Fussy comprehensive evaluation is adopted in the evaluation process. The factor set is

$$U = \{\text{Agricultural output, Industrial output, Fixed assets, Income}\} \tag{1}$$

and the selected fussy remark set is

$$V = \{\text{High, Middle, Low}\} \tag{2}$$

Data value of the 108 counties for each of the four factors is evaluated against these remarks and the result is a subset of V, describing the subordinate of the sample to each remark. The evaluation is based on the fact that economic loss in a flood event is proportional to the economic density of the harzard-stricken area. Evaluation for all the four factors comprise a fussy matrix, which is named as R. The overall evaluation of each sample can be derived by the following fussy transformation equation:

$$B = A \sum\sum R \tag{3}$$

Where A is a fussy subset of U and indicates the weight assignments for the four factors. Since the study area is an agricultural area, damage on agriculture and farmer's fixed assets is given higher importance in the evaluation:

$$A = (0.45,\ 0.15,\ 0.15,\ 0.25) \tag{4}$$

The fussy transformation operator in Equation 3 is (>,<).

The evaluation result shows that Xinxiang, Huojia, Weihui, Yucheng, Pingyuan, Lingxian, Liaocheng, Jiyang, Linyi, Heze, Jinxiang, Yutai, Zhongmo, Tongxu, Fugou, Zhoukou, Bozhou, Guoyang, Mengcheng, Huiyuan and Guzhen Counties have a higher danger magnitude. Many of these counties are the central city of the local prefectures. In general, counties in the upper parts of the alluvial fans of the Yellow River have a higher danger magnitude.

IV. STRATEGIES FOR THE FLOOD PLAIN MANAGEMENT

IV.1 General Strategies for the Flood Plain Management

1. To improve drainage conditions of the flood-prone areas The flood-prone areas on the lower reach of the Yellow River are hazardous areas with many inter-related environmental problems, such as drought, waterlogging and salinization. Drought is a frequent natural hazard and then is given a higher importance in environmental management. For fear of drought, most of rivers and drainage canals are used for the delivery and storage of irrigation water. This results in a serious sedimentation problem of rivers and drainage canals since the water is mostly diverted from the Yellow River, which is high in silt content. Discharging capacity of the 13 main drainage channels in the area has decreased 20 - 50% in the last 20 more years (Qi 1991). Some rivers have lost most of their discharging capacity. In this connection, drainage improvement is of the first significance to the reduction of the damage in the possible dike-outbreak flooding of the Yellow River. Measures for drainage improvement include 1) desilting in the main discharging channels, 2) improving the management of water diversion from the Yellow River and 3) removing obstacles in the main discharging channels, of which the second measure is extremely urgent.

2. To strengthen the construction of safety infrastructure in the flood-prone areas Among the optional measures for flood hazard prevention and loss reduction, restriction on development and land use has little effect in such an populated area as the North China Plain. However, structural flood

prevention measures and flood shelters have their necessity and feasibility. On the other hand, an improved flood warning system is on its way of construction. The system will work only if there is sound safety infrastructure and an emergency rescue system. The construction of safety infrastructure refers to 1) building flood proof measures, 2) establishment of flood shelters and 3) consideration of flood drainage in the planning of communication lines and streets. Adobe houses make up a large proportion of the buildings in rural areas along the Yellow River that are easily collapse in a flooding. In some poor villages, such houses amount to over 80% of the total. Some simple measures like land elevation, closure and seals will enhance greatly the flood-proof ability of the buildings.

3. To establish flood insurance system in the flood-prone areas Insurance is an important disaster relief measures but has long been ignored in China. It is a reliable hazard relief measure for the people in the flood-prone areas and helps the implementation of market economy, since the development of a hazard-prone area bearing its hazard costs is an important principle of resource distribution in a market economy. In recent years, insurance has developed rapidly in China. At present, there are over 100 insurance types in rural areas. Thus it is time to implement flood insurance in the flood-prone areas in the North China Plain. People in the area has low consciousness for dike-outbreak flood danger since 40 more years past without such a hazard. Thus the implementation of flood insurance system is not an easy work in the area, and relevant policies encouraging the purchase of flood insurance should be adopted. The people who purchase the insurance should be given the privilege of obtaining governmental relief funds while a flood hazard happens. For the large enterprises and new construction projects, flood insurance should be regulated as a compulsory one.

4. To draw detailed flood hazard reduction planning A detailed hazard prevention and mitigation planning is essential for the implementation of any engineering and non-engineering measures. There is still a large knowledge and data gap on the progressing processes of the dike-outbreak floods of the Yellow River, and the extent, depth, velocity, silt content and duration of such floods. A flood map at a scale larger than 1:50,000 and contour interval over 0.5 m is urgently needed. The map should provide the information about the courses of main flood currents, silt contents and maximum inundation depth. Safety areas should be also delineated on the map based on the topography of the flood plain, for the construction of safety infrastructure and the design of rescue plans.

IV.2 Flood Plain Management Strategies in Different Flood-prone Areas

1. Flow-impact-dominated type flood-prone areas These areas are close in space to the dikes of the Yellow River and have a large slope gradient. Thus the effect of emergency evacuation is limited in such areas when an out-break flood happens since little time would be left for flood warning. Flood walls and village cofferdams that have revetments on upstream batters are appropriate for flood prevention in these areas. Administrative areas with a high danger magnitude include Wuzhi, Fengqiu, Changyuan, Zhongmou, Dongming and Dong’e Counties and Zhengzhou, Kaifeng and Puyang Municipalities.

2. Waterlogging-dominated type flood-prone areas Flood flows in these areas are characterized by low velocity, shallow depth, but long inundating duration. On the other hand, people has a high consciousness of flooding since the areas are frequently attacked by waterlogging hazards. In this connection, measures like land elevation, closures, seals and standard improvement on building materials have good effect. Besides, drainage improvement is extremely important for flood mitigation in these areas. Administrative areas with a high danger magnitude include Bozhou, Guoyang, Mengcheng, Huaiyan, Guzhen and Taihe Counties in Anhui Province and Fengxian, Peixian and Pixian in Jiangsu Province.

3. Mixed type flood-prone areas These areas have the largest spatial extent among the three types of flood-prone areas and are characterized by a undulating micro-topography. The widely distributed downlands on the plain may be surrounded by water as islands while a flooding happens and become flood shelters. The construction of flood shelter towers and evacuation roads should be attached importance among damage reduction measures. Administrative areas with a high danger magnitude include Linyi, Jiyang, Yanjin, Zixian, Yanggu, Jinxiang and Taikang Counties and Xinxiang, Zhouko, Heze and Yucheng Cities.

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